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Use of soy protein based 1-methylcyclopropene-releasing pads to extend the shelf life of tomato (*Solanum lycopersicum* L.) fruit

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ABSTRACT

In the last years great interest has been devoted to the development of preservation treatments for packed foods. In this work, we developed and tested soy protein biodegradable films releasing the inhibitor of ethylene action 1-methylcyclopropene (1-MCP). Soy protein pads were prepared by casting from formulations containing different glycerol concentrations (20, 40 or 60% on protein basis) and pHs (2.0, 7.0 or 10.0). Their tensile strength, water content and ability to delay tomato ripening were determined. The best performing films (pH 7.0; 20% glycerol) were selected to further characterize the influence of the 1-MCP-releasing pads on tomato texture, color, sugars, acids, antioxidants and decay under different storage regimes. Results showed that soy protein 1-MCP-releasing pads delayed tomato softening and pectin solubilization, reduced decay and lycopene accumulation and could be useful for postharvest "in package" treatments.

Industrial relevance: Controlling ethylene action is crucial to prevent over-ripening. In the last years the inhibitor of ethylene action 1-MCP was launched and since then its use in fruits and vegetables has rapidly expanded. We have developed and evaluated soybean protein pads intended to be used as 1-MCP releasers. When incorporated into tomato fruit packages, the pads delayed ripening without causing negative quality changes. Soy protein based releasers could be useful to perform postharvest treatment during transit or distribution.

1. Introduction

In the last years great interest has been devoted to develop treatments for packed foods (Lopez-Rubio, Gavara, & Lagaron, 2006). Natural antimicrobial agents have been incorporated into edible coatings (Raybaudi-Massilia, Rojas-Graü, Mosqueda-Melgar, & Martín-Belloso, 2008) and active packages to preserve the quality of fresh fruits and vegetables (Tzortzakis, 2007). α-cyclodextrin capsules were used to release antifungal thyme volatiles (Del Toro-Sánchez et al., 2010). Montero-Prado, Rodriguez-Lafuente, and Nerin (2011) developed a label containing cinnamon essential oil, which when attached to plastic peach packages extended their shelf-life.

The control of ethylene production and action is extremely useful to prevent vegetable senescence and ripening of climacteric fruits. Ethylene oxidizers containing $KMnO_4$ are commercially available, but their efficacy under high relative humidity conditions is limited (Terry, Ilkenhans, Poulston, Rowsell, & Smith, 2007). A recent strategy based on the use of 1-metyhylcylopropene (1-MCP) has been developed (Reid & Staby, 2008). 1-MCP binds ethylene receptors reducing the extent of the responses associated with the hormone (Blankenship & Dole, 2003). The active principle is retained in α-cyclodextrin matrix and released when the commercial formulation is mixed with water (Watkins, 2006). 1-MCP treatments are normally performed in cold stores or closed chambers, in which the fruit is maintained for 12 to 24 h (Blankenship & Dole, 2003). A few studies have evaluated other application methods for 1-MCP. Manganaris, Vicente, Crisosto, and Labavithc (2007) found that dips with a liquid formulation of 1-MCP before packing could be useful to delay ripening of plums. Lee, Beaudry, Kim, and Hartec (2006) evaluated low-density polyethylene (LDPE), and polyvinyl acetate (PVA) and paper sachets containing different adsorbents as releasing systems for 1-methylcyclopropene (1-MCP).

The ability of agriculture-derived proteins to generate biodegradable films has been extensively studied (Cuq, Gontard, & Guilbert, 1998; Gennadios, 2002). Besides their use as barriers, biopolymeric films could be designed to release a variety of active principles. Mastromatteo, Barbuzzi, Conte, and Del Nobile (2009) generated zein-based film for controlled volatilization of thyme antimicrobials.

In general, protein films are good barriers to oxygen, lipids and aroma compounds, but have poor mechanical properties and are susceptible to water (Gennadios, 2002). However, film properties depend on the nature of the protein and formulation as well as on processing methods and storage conditions (Denavi et al., 2009; Mauri & Añón,

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2006). The high relative humidity recommended for most fresh fruits and vegetables may result in water absorption by protein films and increase their permeability. While increased gas diffusion could be undesirable for some uses, in other cases it may facilitate active principle release.

One hundred and forty five million tons of tomato fruit are annually produced worldwide (FAOSTAT, 2012). Although low temperature storage is the most common strategy to control ripening, the fruit is susceptible to chilling injury and could not be stored below 7–10 °C. Consequently, it might be of great interest to find complementary strategies such as ethylene control to manage ripening. The aim of the present work was to develop soy protein-based 1-MCP-releasing pads and to evaluate their efficacy as a postharvest in-package treatment to maintain quality and extend the shelf-life of tomato fruit.

2. Materials and methods

2.1. Selection of soy protein film formulation for pad production

2.1.1. Film preparation and physical characterization

The effect of pH and glycerol content on soy protein film's properties was studied in order to select the most suitable formulation to generate a pad that is able to release a gaseous active principle retained in a cyclodextrin matrix (Fig. 1A). Films were prepared by dispersing 5 g of soy protein isolate (SPI, Supro 500E, The Solae Company, Brazil) and 1, 2 or 3 g of glycerol and water to a final volume of 100 mL. The dispersions were stirred for 30 min at 20 °C. Subsequently the pH was adjusted to 2.0; 7.0 or 10.0 with HCl or NaOH 2.0 N and the dispersions were stirred for additional 30 min. Ten milliliters of every film-forming dispersion were poured in polystyrene Petri dishes (64 cm^2) and dried in an oven (Yamato, DKN600, USA) at 60 °C for 3 h. The films were conditioned at 20 °C and 58% relative humidity (RH) in a desiccator equilibrated with saturated NaBr for 48 h before being peeled from the casting surface. In order to evaluate the films after the intended use conditions soybean protein polymers were placed in plastic trays (22.5 × 17.5 × 4.5 cm) containing four breaker stage tomatoes (weighing approximately 600 g each) and covered with PVC (20 μm thick). The trays were stored at 10 °C and 85–90% RH for 36 h. Five trays were prepared for each evaluated formulation. Film thickness, water content, water absorption and mechanical properties were determined as follows:

2.1.1.1. Thickness. Film thickness was measured by a digital coating thickness gauge (Check Line DCN-900, USA). Ten measurements were done for each film formulation evaluated.

2.1.1.2. Moisture content (MC). Film samples were weighed and then dried in an oven at 105 °C until constant weight. MC was determined in triplicate for each film formulation, and calculated as the percentage of weight loss relative to the original weight.

2.1.1.3. Mechanical properties. Film mechanical properties were determined by performing a tensile test according to the ASTM (ASTM, 2004) in a texture analyzer TA.XT2i (Stable Micro Systems, Surrey, England). The films were cut into strips (6 × 80 mm) and mounted with two grips at opposite ends. Grip separation was 50 mm and the cross-head speed was 0.5 mm s^{-1}. The tensile strength and the elongation at break were determined directly from the stress–strain curves using Texture Expert V.1.15 software (Stable Micro Systems, Surrey, England). The Young's modulus (E) was calculated as the initial slope. Six measurements were done for each formulation.

2.1.2. Effect of different formulations of 1-MCP releasers on tomato fruit color and firmness

Tomato fruits (*Solanum lycopersicum* L. cv Elpida) were harvested at the breaker stage and immediately transported to the laboratory. Fruits having blemishes, wounds or any other defects were discarded. Four fruits (weighing approximately 150 g each) were put into plastic trays (22.5 × 17.5 × 4.5 cm). For 1-MCP-releasing pad preparation, protein films obtained with the different formulations and conditioned for 2 days at 58% RH were cut into squares (2 × 2 cm). One milligram of Smart-Fresh® (AgroFresh, Springhouse, PA), containing 0.14% 1-MCP in a cyclodextrin matrix was weighed over a film and subsequently covered with a second protein film layer. The film surfaces were then thermo-sealed to generate 8 cm^2 protein film pads containing the 1-MCP (Fig. 1A). For each formulation, six trays with a releasing pad and covered with PVC were prepared (Fig. 1B). Corresponding fruit trays without protein pad but packed and stored as described above were used as controls. The trays were stored at 10 °C (85–90% RH) for 36 h and subsequently opened and held at 20 °C for 5 days. Fruit surface color and firmness were evaluated as follows:

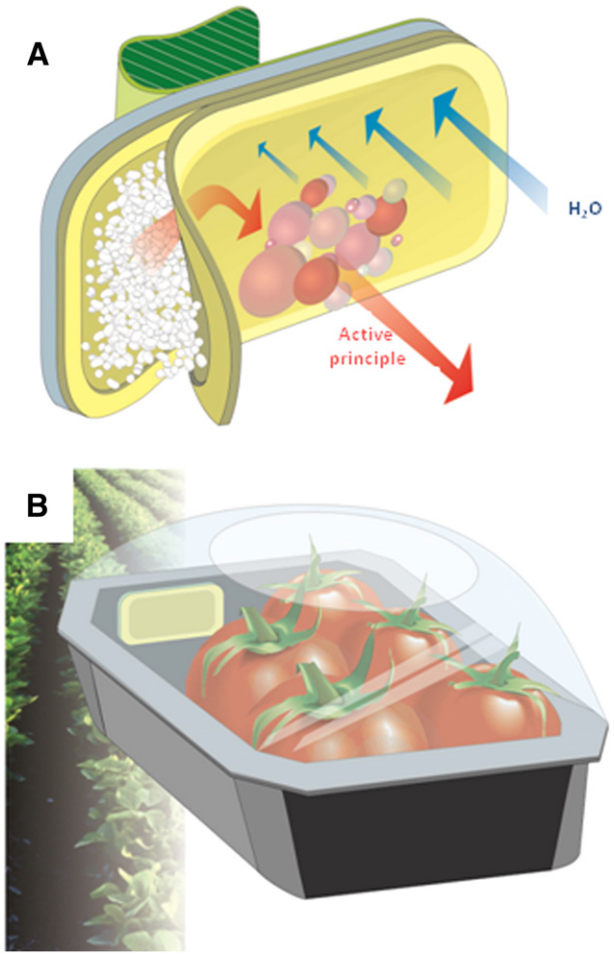

Fig. 1. A. Design of the soybean protein-releasing pad containing an active principle retained in a cyclodextrin matrix and B. intended use of the soybean protein-releasing pads containing 1-MCP in a cyclodextrin matrix for "in package" treatment of tomato fruit.

2.1.2.1. Color. The L*, a* and b* chromaticity values were determined with a Minolta colorimeter, Model CR-400 (Minolta, Osaka, Japan) and the hue angle (tg^{-1} b*/a*) was calculated. Color was measured in the fruit equatorial zone and twenty four measurements were done for each formulation.

2.1.2.2. Firmness. Firmness was determined in a Texture Analyzer (TA.XT2, Stable Micro Systems Texture Technologies, Scarsdale, NY, USA) by compressing the fruit tissue 5 mm in equatorial zone, at a rate of 0.5 mm s^{-1} with a 3-mm-diameter flat probe. The initial slope of the compression plots was calculated. Forty eight measurements

were done for each treatment and storage time. Results were expressed in Newton per millimeter.

2.2. Quality of tomato fruit packed with 1-MCP-releasing pads during postharvest storage

Once the appropriate soy protein film formulation was determined, we evaluated the effect of the selected 1-MCP releasers on tomato fruit quality maintenance. Protein pads (pH 7.0, 20% glycerol SPI) containing 1 mg of 1-MCP were put into trays containing four fruits and covered with PVC as previously described (Fig. 1B). The trays were stored at 10 °C (≈90% RH) for 1, 8 or 16 days, subsequently opened and transferred to 20 °C for 5 days. Corresponding control trays without 1-MCP-releasing pads were prepared and stored under the same conditions. Ten trays were used for each treatment and storage time. The whole experiment was repeated twice. Measurements were immediately done after sampling or otherwise fruit tissue was frozen in liquid N_2 and stored at −80 °C until used for quality evaluation.

2.2.1. Decay

The percentage of decayed fruits was determined. Eighty fruits were evaluated for each treatment.

2.2.2. Weight loss

Weight loss was determined by weighing individual fruits at the beginning of the experiment and after storage. Weight loss (WL) was calculated as: $WL = 100 \times (W_i - W_f) / W_i$, W_i being the initial sample weight and W_f the final sample weight. Results were expressed as percentage weight loss. Forty measurements were done for each treatment and storage time.

2.2.3. Color and firmness

Surface color and fruit firmness were determined as described in Section 2.1.2.

2.2.4. Lycopene

Fruit tissue was frozen in liquid N_2 and processed in a mill (Model A11, IKA Works Inc., SP Brazil) and 0.25 g of the resulting powder was placed in test tubes containing 5 mL of hexane:acetone:ethanol (2:1:1). The sample was vortexed and maintained at 4 °C for 30 min. After that 1 mL of water was added, and the absorbance of the upper phase was measured in a spectrophotometer (Beckman, Model UV Mini-1240, CA, USA) at 503 nm. Measurements were done in triplicate and results were calculated by using $\varepsilon = 172{,}000\ M^{-1}\ cm^{-1}$ (Taber et al., 2008) and expressed as milligram of lycopene per kilogram of fresh weight.

2.2.5. Water soluble pectin (WSP)

Fruit tissue was ground with 20 mL of water in an Omni mixer. The suspension was vortexed, centrifuged at 10,000 ×*g* for 10 min at 4 °C. Three extractions were done for each treatment and storage time. The concentration of uronic acids in the WSP was determined as previously reported (Blumenkrantz & Asboe-Hansen, 1973). Results were expressed as grams of galacturonic acid per kilogram of fresh fruit.

2.2.6. Sugars

Frozen tissue was processed in a mill (Model A11, IKA Works Inc., SP Brazil), and 1 g of the resulting powder was extracted with 5 mL of ethanol. The mixture was vortexed, centrifuged at 17,000 ×*g* for 10 min at 4 °C, and the supernatant was taken to 100 mL water. Sugars were measured with the anthrone reagent (Yemm & Willis, 1954). Briefly, aliquots (50 μL) of the ethanolic extracts were brought to 500 μL water. One milliliter of 2 g L^{-1} anthrone, prepared in 98% (w/w) H_2SO_4, was added slowly to the test tubes in a water–ice bath. The samples were then heated at 100 °C for 10 min, cooled in water and the absorbance at 620 nm was measured in a spectrophotometer. Glucose was used as a standard and results were expressed in g kg^{-1}. Four measurements were done for each treatment and storage time.

2.2.7. Acidity

Ten grams of fruit pulp was ground in a mill and dispersed in 100 mL of water. Samples were titrated with 0.1 mol L^{-1} NaOH until pH 8.2 (AOAC, 1980). Four measurements were done for each treatment and storage time. Results were expressed as $[H^+]$ mmol kg^{-1}.

2.2.8. Antioxidants

Frozen fruit tissue was ground in a mill and approximately 1 g of the resulting powder was vortexed for 1 min in 5 mL of cold ethanol and centrifuged at 15,000 ×*g* for 10 min at 4 °C. The supernatant was used for subsequent antioxidant determinations. The DPPH• assay was done according to the method of Brand-Williams, Cuvelier, and Berset (1995) with minor modifications. Different aliquots (0–50 μL) of fruit ethanol extracts were diluted to 80 μL water. After that 500 μL of a 60 mg L^{-1} solution of the radical DPPH• in ethanol was added. Samples were vortexed and incubated at 20 °C for 90 min in darkness. The absorbance at 515 nm was measured and the amount of extract required to consume 50% of the initial DPPH• was calculated (EC_{50}). The antioxidant capacity was defined as EC_{50}^{-1} in mg^{-1}. Three measurements were done for each treatment and storage time.

2.2.9. Respiration rate

Two fruits weighing approximately 300 g were incubated in a hermetic flask (3 L) for 20 min at 20 °C. Fruit CO_2 production was measured with an infrared sensor (Alnor Compu-flow, Model 8650, Alnor, USA). Measurements were done in triplicate for each treatment and storage time. Results were expressed in milliliter of CO_2 released per kilogram of fresh fruit in an hour.

2.3. Statistical analysis

Experiments were performed according to a factorial design. Data was analyzed by means of ANOVA. The main effects and the interactions were analyzed and the means were compared by the LSD test at a significance level of 0.05.

3. Results and discussion

3.1. Selection of soy protein film formulation

To select the optimal formulation for soy protein 1-MCP-releasing pads we evaluated the effect of the pH and glycerol content on film tensile strength and water content before and after storage within fruit packages. Glycerol is a hydrophilic plasticizer commonly used in protein films. By increasing polypeptide molecular spacing, it overcomes the brittleness of pure protein films (Gennadios, 2002). Proteins exposed to different pH undergo structural changes that affect the intermolecular interactions and consequently the film properties. As the concentration of the plasticizer was raised the tensile modulus decreased (Fig. 2A). Films containing 40 or 60% glycerol did not show variations in the mechanical properties, regardless of pH. In contrast 20% glycerol films showed different strength depending on the H^+ concentration. The greater tensile modulus was found at pH 7.0. This differs from the results reported by Mauri and Añón (2006, 2008), who found better mechanical properties at extreme pHs (2.0 and 10.5). However, it is important to point out that they used seed protein isolates in which native proteins are predominant (Denavi et al., 2009). Gennadios, Brandenburg, Weller, and Testin (1993) found that commercial SPI films at pH 6–11 had superior mechanical properties (higher elongation before breakage and tensile strength) than films at pH 1–3. This may have resulted from a greater prevalence of disulfide bonds, which are normally favored at neutral and alkaline conditions (Darby & Creighton, 1995).

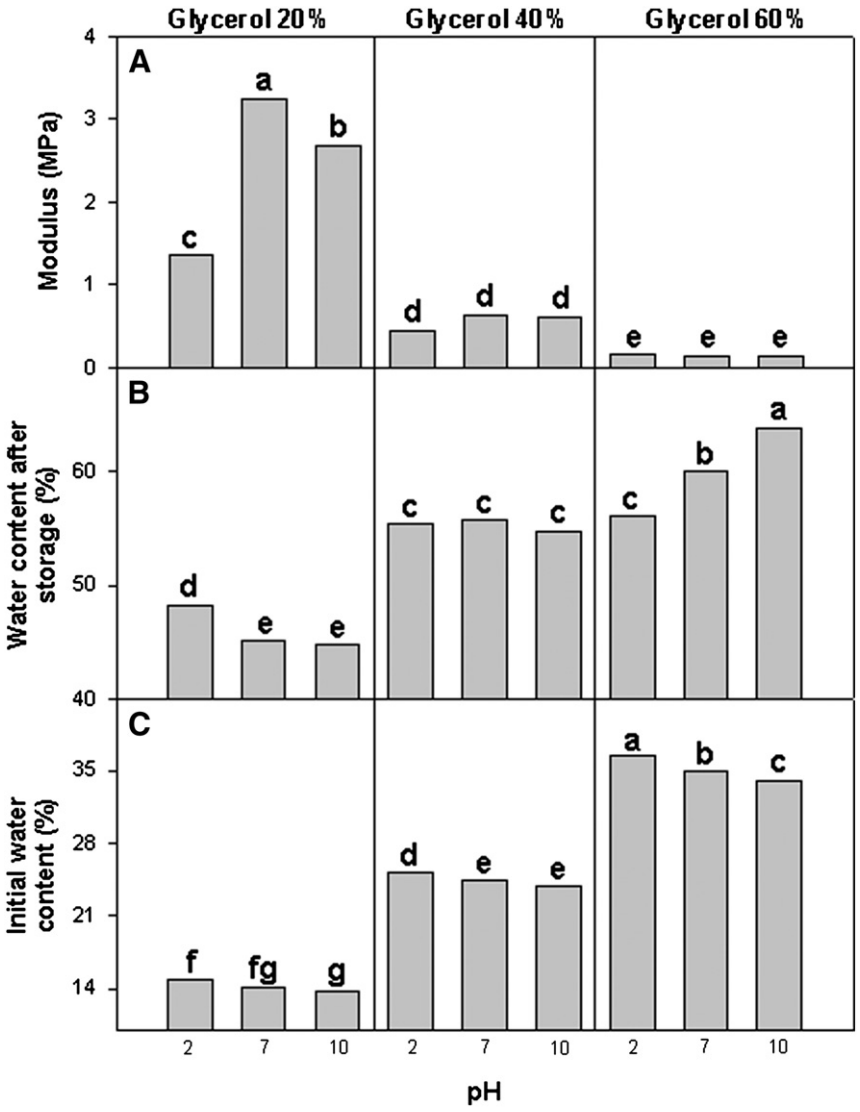

Fig. 2. A. Modulus and B. water content of films after 36 h of storage at 10 °C in trays containing breaker stage tomato fruit (600 g) and covered with PVC. C. Water content (on dry weight basis) of soy protein films prepared 20, 40 or 60% on a protein basis and adjusted to pHs (2.0, 7.0 or 10.0) before use. Different letters indicate differences based on a LSD test at a level of significance of $P \leq 0.05$.

Glycerol may affect both water retention and uptake (Kowalczyk & Baraniak, 2011; Lim, Mine, & Tung, 1999). High water retention prior to use may be undesirable since it could reduce the stability of the active principles. Increasing glycerol content led to higher water content after storage (Fig. 2B). However, these films presented elevated water contents already before use (Fig. 2C).

Postharvest 1-MCP treatments are normally performed in hermetic chambers before fruit packing for 12 to 24 h. In tomato, they have been effective to delay ripening and reduce spoilage (Moretti, Araujo, Marouelli, & Silva, 2002; Mostofi, Toivonen, Lessani, Babalar, & Lu, 2003). We wanted to determine whether or not the different films showed variations in their 1-MCP-releasing capacity. Consequently, we prepared trays containing tomato fruit covered with PVC (20 μm thick) either with or without the pads (control) and followed the changes in firmness and color. Water is required to hydrate cyclodextrin and release 1-MCP. Consequently high initial water contents may cause extensive active principle losses before use. However, the efficacy of the pads was not compromised even in the films showing the highest initial water contents (60% glycerol) (Fig. 3). Although further evaluations are required, this suggests that no substantial 1-MCP losses occurred. In spite of their lower water content after use (Fig. 2B), the efficacy of 20% glycerol pads was comparable to that of films containing higher plasticizer. This indicates that water uptake in these films was sufficient to release the active principle.

The pH caused greater effects on pad's efficacy than glycerol concentration. The ability of the films at pH 10.0 to maintain lightness (Fig. 3A), delay color development (Fig. 3B), and softening (Fig. 3C) was lower than that of neutral or acid pads. Mauri and Añón (2006) studied the influence of the pH on the structural and functional properties of native soy protein films. The relevance of covalent and non-covalent interactions stabilizing the protein network was markedly affected by the pH. Alkaline films were more hydrophilic than those prepared at acidic pH. Though further studies would be necessary to fully address this, the lowest efficacy of alkaline films may have resulted either from excessive film permeability or 1-MCP instability. Based on the better mechanical properties, lower initial water content and efficacy to delay ripening, we selected soy protein films with 20% glycerol as the most suitable for 1-MCP release. Moreover, since neutral films improved better mechanical properties and would potentially be more compatible with other active principles we performed subsequent experiments with film suspensions at pH 7.0.

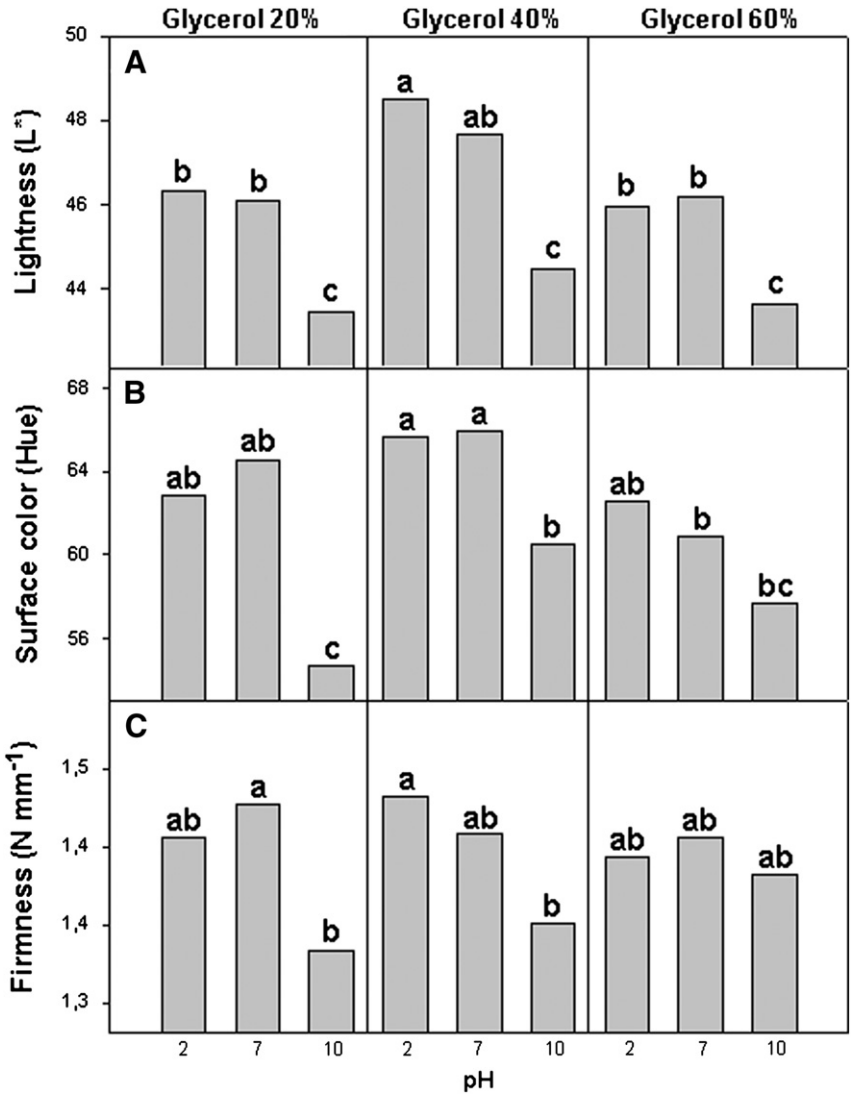

Fig. 3. A. Lightness (L*), B. surface color tone (hue), and C. firmness (N mm^{-1}) of tomato fruit (breaker stage) stored in plastic trays covered with PVC film without (control) or with 1-MCP-releasing-pads prepared with different concentrations of glycerol (20, 40 or 60% on a protein basis) and at different pHs (2, 7 or 10), and stored at 10 °C for 7 days. Different letters indicate differences based on a LSD test at a level of significance of $P \leq 0.05$.

3.2. Quality of tomato fruit packed with 1-MCP-releasing pads during postharvest storage

A second set of experiments was performed to evaluate the effects of the selected 1-MCP-releasing pads (20% glycerol on protein basis and pH 7.0) on tomato fruit decay, organoleptic and nutritional quality under different storage regimes. Hotchkiss, Watkins, and Sanchez (2007) incorporated a 1-MCP/α-cyclodextrin complex into several common packaging films by heat-pressing. However excessive heat treatments can greatly reduce the stability of gaseous compounds retained in cyclodextrin matrices (Astray, Gonzalez-Barreiro, Mejuto, Rial-Otero, & Simal-Gándara, 2009). In our work the 1-MCP is incorporated after film production avoiding exposure to high temperatures. The selected 1-MCP-releasing pads were put in trays containing tomatoes, covered with PVC, stored for three different time points at 10 °C and subsequently transferred to 20 °C for 5 days. Corresponding control trays without pads were evaluated. Lower percentage of decayed fruits was found in the packages with the 1-MCP-releasing pads (Fig. 4A). After 15 days at 10 °C and 3 days at 20 °C 15% of the control fruits showed some decay signs as compared to 3% of 1-MCP treated tomatoes. Susceptibility to fungal attack is known to increase rapidly as fruits develop (Cantu, Vicente, Labavitch, Bennett, & Powell, 2008). The reduced decay incidence in 1-MCP treated fruits may then have resulted from ripening delay (Fig. 4B). Weight loss increased during storage and after 1 or 8 days at 10 °C and 5 days at 20 °C was close to 4% in both control and treated fruits (Table 1). After 16 days at 10 °C and 5 days at 20 °C weight loss was 6% and no differences between control and 1-MCP treated fruits were detected either. The 1-MCP treatments did not cause modifications in fruit respiration (Table 1), but reduced the ripening rate at all storage times. After 1 or 8 days at 10 °C and 5 days at 20 °C the lightness of 1-MCP treated fruits was higher than that of the control (Fig. 5A). The hue angle decreased during storage, but was similar in control and 1-MCP treated fruits indicating no change in fruit color tone (Fig. 5B). However, the lower lycopene content observed in treated fruit confirmed that ripening was slowed down by the use of the releasing pads (Fig. 5C). It is worth noting that after 16 days at 10 °C and 5 days at 20 °C the differences in color development between control and treated fruits were minimal. This is technologically important, since full ripening is needed to reach organoleptic maturity.

The distance to tissue failure compression tests was not affected (Fig. 6A), but 1-MCP treated tomatoes showed higher resistance to penetration than the control (Fig. 6B). The reduced texture loss of control tomatoes was also associated with lower solubilization of pectins (Fig. 6C).

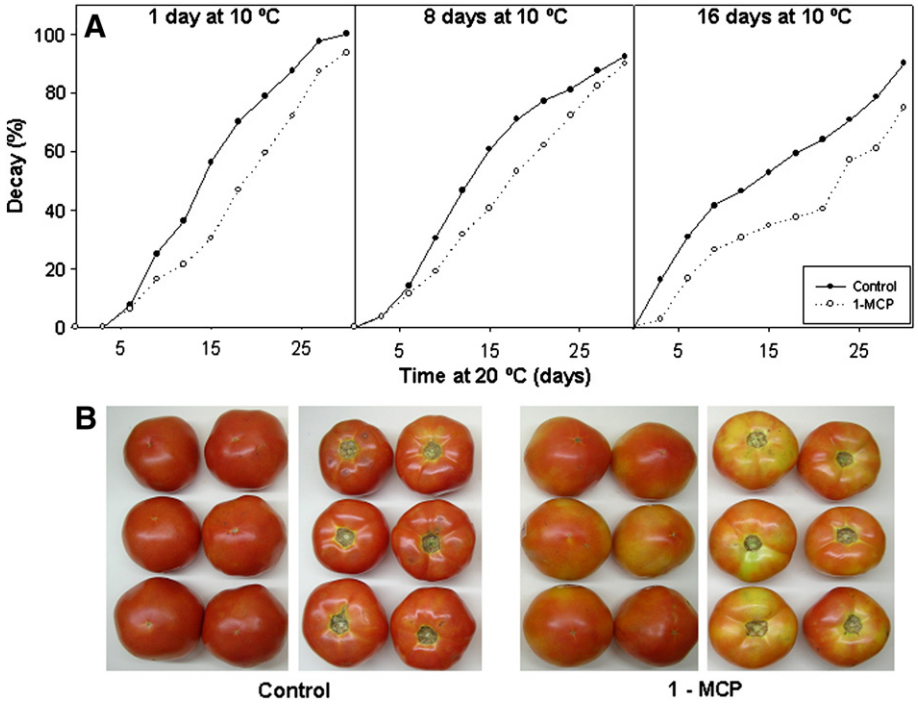

Fig. 4. A. Decay of tomato fruit (breaker stage) stored in plastic trays covered with PVC film without (control) or with 1-MCP-releasing-pads (pH 7 and 20% glycerol on protein basis) stored at 10 °C for 1, 8 or 16 days and subsequently transferred to 20 °C. B. Appearance of control or "in package" 1-MCP treated fruits after 8 days of storage at 10 °C.

The 1-MCP treatments did not cause undesirable modifications in sugar content or acidity. Finally, the content of hydrophilic antioxidants was similar in control and treated fruits (Table 1).

4. Conclusion

Water uptake by protein films might be undesirable for certain applications. However, it could be exploited as an advantageous property aiding in the release of active principles for "in package" treatments of foods. In this work a formulation based on soy protein isolates and glycerol was selected to prepare biodegradable films and generate releasers of 1-methylcyclorpropene, an ethylene action inhibitor. The protein-releasing pads were evaluated based on their efficacy to delay ripening and prevent tomato postharvest deterioration. When incorporated into

Table 1
Weight loss, respiration, acidity, sugars and antioxidants of tomato fruit (breaker stage) stored in plastic trays covered with PVC film without (control) or with 1-MCP-releasing-pads (pH 7 and 20% glycerol on protein basis) stored at 10 °C for 1, 8 or 16 days and subsequently transferred to 20 °C for 5 days. Different letters indicate significant differences based on a LSD test at a level of significance of $P \leq 0.05$.

		Storage regimes			
		Harvest	1 day 10 °C + 5 days 20 °C	8 days 10 °C + 5 days 20 °C	16 days 10 °C + 5 days 20 °C
Weight loss (%)	Control	0.00	3.68a	4.00a	5.76b
	1-MCP	0.00	3.67a	3.93a	4.38b
Acidity (mmol kg^{-1})	Control	93.98a	77.85b	78.77b	72.79b
	1-MCP	95.88a	84.30b	79.70b	76.01b
Sugars (g kg^{-1})	Control	24.77a	26.09a	25.97a	23.90a
	1-MCP	26.53a	25.53a	23.11a	22.71a
Antioxidants (mg^{-1})	Control	0.080a	0.086a	0.081a	0.096b
	1-MCP	0.086a	0.080a	0.081a	0.095b
Respiration (mL kg^{-1} h^{-1})	Control	23.62a	13.07b	12.65b	10.91b
	1-MCP	22.89a	12.65b	10.78b	10.52b

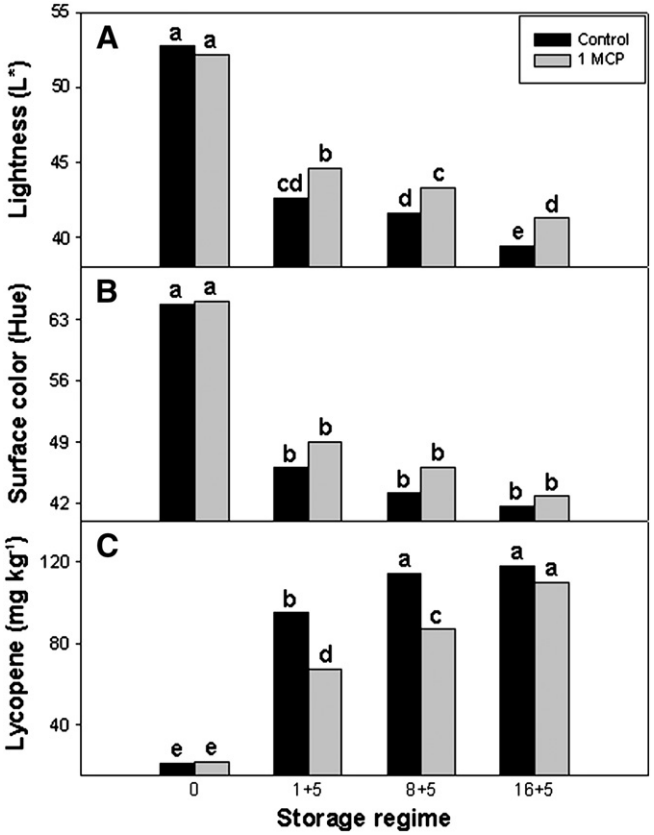

Fig. 5. A. Lightness, B. surface tone (hue), and C. lycopene content of tomato fruit (breaker stage) stored in plastic trays covered with PVC film without (control) or with 1-MCP-releasing-pads (pH 7 and 20% glycerol on protein basis) stored at 10 °C for 1, 8 or 16 days and subsequently transferred to 20 °C. Different letters indicate differences based on a LSD test at a level of significance of $P \leq 0.05$.

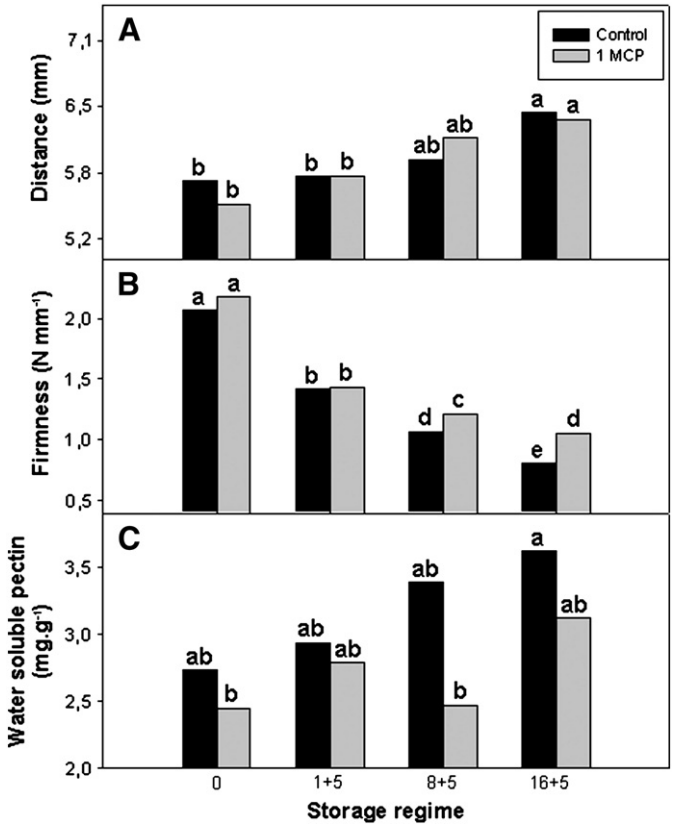

Fig. 6. A. Distance to failure, B. firmness (resistance to penetration), and C. water soluble pectins of tomato fruit (breaker stage) stored in plastic trays covered with PVC film without (control) or with 1-MCP-releasing-pads (pH 7 and 20% glycerol on protein basis) stored at 10 °C for 1, 8 or 16 days and subsequently transferred to 20 °C. Different letters indicate differences based on a LSD test at a level of significance of $P \leq 0.05$.

fruit packages, the pads delayed ripening and reduced softening, pectin solubilization and decay without causing negative quality changes in sugar content, acidity or antioxidants. Results suggest that soy protein based releasers could be useful to perform postharvest treatment during transit or distribution. Future studies could be necessary to continue the evaluation of these materials in commercial packages, under continuous refrigerated storage and to determine the active principle release efficiency.

Acknowledgments

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